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PROVISIONAL APPLICATION FOR PATENT COVER SHEET

This is a request for filing a PROVISIONAL APPLICATION FOR PATENT under 37 CFR 1.53(c).

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TITLE OF THE INVENTION (280 characters max)

OMNIDIRECTIONAL AND FORWARD-LOOKING IMAGING DEVICE

Direct all correspondence to: **CORRESPONDENCE ADDRESS**

☐ Customer Number [ ] → *Place Customer Number Bar Code Label here*

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ENCLOSED APPLICATION PARTS (*check all that apply*)

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☐ Application Data Sheet. See 37 CFR 1.76

METHOD OF PAYMENT OF FILING FEES FOR THIS PROVISIONAL APPLICATION FOR PATENT (check one)

☒ Applicant claims small entity status. See 37 CFR 1.27.

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The invention was made by an agency of the United States Government or under a contract with an agency of the United States Government.

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Respectfully submitted,

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Date May 14, 2004

REGISTRATION NO. 24,156 *(if appropriate)*

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USE ONLY FOR FILING A PROVISIONAL APPLICATION FOR PATENT

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Additional Page

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Docket Number	206,539	Type a plus sign (+) inside this box →	+

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Number 2 of 2

OMNIDIRECTIONAL AND FORWARD-LOOKING IMAGING DEVICE

FIELD OF THE INVENTION

The present invention relates generally to medical devices, and specifically to endoscopic medical devices.

BACKGROUND OF THE INVENTION

Medical endoscopes are used to inspect regions within the body, such as cavities, organs, and joints. Endoscopes typically include a rigid or flexible elongated insertion tube having a set of optical fibers that extend from a proximal handle through the insertion tube to the distal viewing tip of the endoscope. Alternatively, an image sensor, such as a CCD, is positioned near the distal viewing tip. An external or internal light source provides light to the area of interest in the body in the vicinity of the distal tip.

US Patent 6,028,719 to Beckstead et al., which is incorporated herein by reference, describes an imaging system that comprises a panoramic imaging element. The panoramic imaging element is described as being capable of imaging a full 360 degree panoramic image and a forward image onto a single plane.

US Patent 6,704,148 to Kumata, which is incorporated herein by reference, describes an omnidirectional imaging device including a retainer having a top section, a body section, and a bottom section. A mirror having a surface of revolution is mounted on the top portion of the body section. The bottom section is assembled with a mounting base for movably mounting an image pickup device, and with a fixture for fixing the image pickup device to the mounting base.

US Patent 4,976,524 to Chiba, which is incorporated herein by reference, describes an optical system for endoscopes including at least one convex or concave aspheric surface, and a reflecting mirror arranged on the front side of the imaging optical system and having a reflecting surface shaped like a spherical or aspheric surface.

US Patent 6,388,820 to Wallerstein et al., which is incorporated herein by reference, describes a panoramic imaging arrangement that includes at least a first lens block including a convex reflective surface and a transparent component. The convex reflective surface has a substantially vertically extending axis of revolution which is described as being capable of receiving light from a 360 degree surrounding panoramic scene, and reflecting the light for further manipulation. The transparent component covers the convex reflective surface. The convex reflective surface is thereby protected from environmental conditions which may otherwise result in damage to the convex reflective surface.

US Patent 6,611,282 to Trubko et al., which is incorporated herein by reference, describes a system for capturing super wide-angle panoramic images. In particular, a two-reflector system is described which is substantially self-correcting in which optical aberrations are substantially eliminated, such as field curvature, astigmatism and the like. In an embodiment of the invention, two reflectors (e.g., one a hyperboloidal mirror, the other a concave ellipsoidal or spherical mirror), a relay system (e.g., optics such as a mirror, a lens, or a pinhole), and an image sensor are provided.

US Patent 6,333,826 to Charles, which is incorporated herein by reference, describes an omniramic wide angle

optical system comprising a Cassegrain system having a strongly curved convex reflecting surface with a prolate aspheric figure, a secondary reflector surface, and a modular imaging and correcting lens system. Also described is the conversion of a two dimensional annular image or a segment thereof to a viewable horizontal image or a subset thereof, or from a horizontal format image or a subset thereof into an annular image or a segment thereof.

US Patent 6,449,103 to Charles, which is incorporated herein by reference, describes an omnidirectional wide angle optical system comprising an external refracting surface which may be strongly curved, a strongly curved internal primary reflector surface, a secondary reflector surface, central wide angle refracting optics, a modular or integral imaging and correcting lens system which may have aperture adjustment means, and mounting components. Optical surfaces associated with the formation of an omnidirectional virtual image are typically integrated into a single solid catadioptric optic in some embodiments, but central or peripheral wide angle refracting optics which may provide supplemental coverage are separate optical elements in other embodiments.

US Patent 6,157,018 to Ishiguro et al., which is incorporated herein by reference, describes an omnidirectional vision sensor that comprises a rotationally symmetrical convex mirror and a camera arranged opposite the mirror. The rays of light which internally reflect inside the cylinder pass through the production line of the rotational axis of the convex mirror, and are thus eliminated before they reach the inner surface of the transparent cylinder. A tapered object on the vertex of the convex mirror is described as completely eliminating inner reflected rays of light.

US Patent Application Publication 2002/0109773 to Kuriyama et al., which is incorporated herein by reference, describes an imaging device that includes a convex mirror for reflecting first incident light representing an object, the convex mirror having a shape of a solid of revolution; an imaging mechanism for capturing a reflected image represented by light reflected in the convex mirror; and an optical member for guiding the first incident light toward the convex mirror and guiding the reflected light toward the imaging mechanism. The optical member has an attenuation section for attenuating second incident light which (a) is incident on an outer circumferential surface of the optical member in a direction opposite the first incident light, (b) passes through the optical member, (c) is reflected by an inner circumferential surface of the optical member so as to be directed toward the convex rotational mirror, and (d) is superimposed on the first incident light.

US Patent Application Publication 2002/0109772 to Kuriyama et al., which is incorporated herein by reference, describes an imaging device including a convex mirror for reflecting incident light representing an object, the convex mirror having a shape of solid of revolution; an imaging mechanism for taking an image represented by reflected light from the convex mirror; and an optical member for guiding the incident light toward the convex mirror and guiding the reflected light toward the imaging mechanism, the optical member being in close contact with the convex mirror.

PCT Publication WO 02/059676 to Gal et al., which is incorporated herein by reference, describes a spherical view imaging apparatus comprising an axisymmetric form comprising a transparent lateral surface, a first end

surface, and a second end surface; a first lens positioned substantially perpendicular to and concentric with the axis of the axisymmetric form to the side of the first end surface; a second lens positioned substantially perpendicular to and concentric with the axis of the axisymmetric form on the side of the second end surface; and an image acquiring device positioned substantially coaxially with the second lens and beyond the second lens with respect to the second end surface.

PCT Publication WO 03/026272 to Gal et al., which is incorporated herein by reference, describes an imaging assembly comprising a first, essentially symmetric reflective surface, having a shape suitable to reflect a substantially panoramic view of an area surrounding it, and a second reflective surface, which is asymmetric with respect to said first reflective surface, i.e., which is positioned, with respect to the axis of symmetry of said first reflective surface, such that its movement in one or more directions reflects different portions of the area reflected by said first reflective surface, and the optical properties of said second reflective surface are such that area imaged by it is magnified with respect to the same portion of the area imaged by the first reflective surface.

PCT Publication WO 02/075348 to Gal et al., which is incorporated herein by reference, describes a method for determining azimuth and elevation angles of a radiation source or other physical objects located anywhere within an cylindrical field of view. The method uses an omni-directional imaging system including reflective surfaces, an image sensor, and an optional optical filter for filtration of the desired wavelengths. Use of two such systems separated by a known distance, each providing a different reading of azimuth and elevation angle of the

same object, enables classic triangulation for determination of the actual location of the object.

PCT Publication WO 03/046830 to Gal et al., which is incorporated herein by reference, describes a self-contained omnidirectional imaging device. The device contains within it all mechanic, electronic, optic and electro-optic components required for its operation, namely: omnidirectional optics, image capture device, power source, illumination sources, transmitters, receivers, and additional optional elements for enhanced capabilities. In an embodiment, the device is housed inside a spherical structure, designed for deployment to potentially hazardous environments, in order to enable omnidirectional viewing of such environments without endangering the viewer.

US Patent Application 2004/0004836 to Dubuc, which is incorporated herein by reference, describes an internal reflection element having a plurality of internal reflection faces and a plurality of exit faces which redirect light from a light source into a side direction. The curved entry faces have the optical effect of concentrating incident light onto a center of the corresponding internal reflection face. This is described as allowing light impinging on the internal reflection face from a wide range of angles to be redirected for side projection through the desired exit face.

SUMMARY OF THE INVENTION

In embodiments of the present invention, an optical system for use with a device comprises an optical assembly and an image sensor, such as a CCD or CMOS sensor. Typically, the device comprises an endoscope for insertion in a lumen. For some applications, the endoscope comprises a colonoscope, and the lumen includes a colon of a patient. The optical assembly typically comprises an optical member having a rotational shape, at least a distal portion of which is shaped so as to define a curved lateral surface. A distal (forward) end of the optical assembly comprises a convex mirror having a rotational shape that has the same rotation axis as the optical member. (The mirror is labeled "convex" because, as described hereinbelow with reference to the figures, a convex surface of the mirror reflects light striking the mirror, thereby directing the light towards the image sensor.)

The optical system is configured to enable simultaneous forward and omnidirectional lateral viewing. Light arriving from the forward end of the optical member, and light arriving from the lateral surface of the optical member travel through substantially separate, non-overlapping optical paths. The forward light and the lateral light are typically processed to create two separate images, rather than a unified image. The optical assembly is typically configured to provide different levels of magnification for the forward light and the lateral light. For some applications, the forward view is used primarily for navigation within a body region, while the omnidirectional lateral view is used primarily for inspection of the body region. In these applications, the optically assembly is typically configured such that the

magnification of the forward light is less than that of the lateral light.

The optical member is typically shaped so as to define a distal indentation at the distal end of the optical member, i.e., through a central portion of the mirror. A proximal surface of the distal indentation is shaped so as to define a lens that focuses light passing therethrough. In addition, for some applications, the optical member is shaped so as to define a proximal indentation at the proximal end of the optical member. At least a portion of the proximal indentation is shaped so as to define a lens. It is noted that for some applications, the optical member is shaped so as to define a distal protrusion, instead of a distal indentation. Alternatively, the optical member is shaped so as to define a surface (refracting or non-refracting) that is generally flush with the mirror, and which allows light to pass therethrough.

In some embodiments of the present invention, the optical assembly further comprises a distal lens that has the same rotation axis as the optical member. The distal lens focuses light arriving from the forward direction onto the proximal surface of the distal indentation. For some applications, the optical assembly further comprises one or more proximal lenses, e.g., two proximal lenses. The proximal lenses are positioned between the optical member and the image sensor, so as to focus light from the optical member onto the image sensor.

In some embodiments of the present invention, the optical system comprises a light source, which comprises two concentric rings of LEDs encircling the optical member: a side-lighting LED ring and a forward-lighting LED ring. The LEDs of the side-lighting LED ring are oriented such that they illuminate laterally, in order to provide

illumination for omnidirectional lateral viewing by the optical system. The LEDs of the forward-lighting LED ring are oriented such that they illuminate in a forward direction, by directing light through the optical member and the distal lens. For some applications, the light source further comprises one or more beam shapers and/or diffusers to narrow or broaden, respectively, the light beams emitted by the LEDs.

Alternatively, the light source comprises a side-lighting LED ring encircling the optical member, and a forward-lighting LED ring positioned in a vicinity of a distal end of the optical member. The LEDs of the forward-lighting LED ring are oriented such that they illuminate in a forward direction. The light source typically provides power to the forward LEDs over at least one power cable, which typically passes along the side of the optical member. For some applications, the power cable is oriented diagonally with respect to a rotation axis of the optical member. Because of movement of the optical system through the lumen, such a diagonal orientation minimizes or eliminates visual interference that otherwise may be caused by the power cable.

In some embodiments of the present invention, the optical system is configured to alternatingly activate the side-lighting and forward-lighting light sources. Image processing circuitry of the endoscope is configured to process forward viewing images only when the forward-viewing light source is illuminated and the side-viewing light source is not illuminated, and to process lateral images only when the side-lighting light source is illuminated and the forward-viewing light source is not illuminated. Such toggling typically reduces any interference that may be caused by reflections caused by

the other light source, and/or reduces power consumption and heat generation.

In some embodiments of the present invention, image processing circuitry is configured to capture a series of longitudinally-arranged image segments of an internal wall of a lumen in a subject, while the optical system is moving through the lumen (i.e., being either withdrawn or inserted). The image processing circuitry stitches together individual image segments into a combined continuous image. This image capture and processing technique generally enables higher-magnification imaging than is possible using conventional techniques, *ceteris paribus*. Using conventional techniques, a relatively wide area must generally be captured simultaneously in order to provide a useful image to the physician. In contrast, the techniques described herein enable the display of such a wide area while only capturing relatively narrow image segments. This enables the optics of the optical system to be focused narrowly on an area of wall having a width approximately equal to that of each image segment.

In some embodiments of the present invention, image processing circuitry produces a stereoscopic image by capturing two images of each point of interest from two respective viewpoints while the optical system is moving, e.g., through a lumen in a subject. For each set of two images, the location of the optical system is determined. Using this location information, the image processing software processes the two images in order to generate a stereoscopic image.

In some embodiments of the present invention, image processing circuitry converts a lateral omnidirectional image of a lumen in a subject to a two-dimensional image. Typically, the image processing circuitry longitudinally

cuts the omnidirectional image, and then unrolls the omnidirectional image onto a single plane.

There is therefore provided, in accordance with an embodiment of the present invention, apparatus including an optical system for use in an endoscope, the optical system having distal and proximal ends and including:

an image sensor, positioned at the proximal end of the optical system;

an optical member having distal and proximal ends, and shaped so as to define:

a lateral surface, at least a distal portion of which is curved, configured to provide omnidirectional lateral viewing,

a distal indentation in the distal end of the optical member, and

a proximal indentation in the proximal end of the optical member;

a convex mirror, coupled to the distal end of the optical member, and shaped so as define an opening through which the distal indentation passes; and

a distal lens, positioned distal to the mirror,

wherein the optical member, the mirror, and the distal lens have respective rotational shapes about a common rotation axis, and

wherein the optical member and the distal lens are configured to provide different levels of magnification for distal light arriving at the image sensor through the distal end of the optical system, and lateral light arriving at the image sensor through the curved distal portion of the lateral surface of the optical member.

There is also provided, in accordance with an embodiment of the present invention, apparatus including an

optical system for use in an endoscope, the optical system having distal and proximal ends and including:

an image sensor, positioned at the proximal end of the optical system;

an optical member having distal and proximal ends, and shaped so as to define:

a lateral surface, at least a distal portion of which is curved, configured to provide omnidirectional lateral viewing, and

a distal indentation in the distal end of the optical member, the indentation shaped so as to define a lens at a proximal surface thereof; and

a convex mirror, coupled to the distal end of the optical member, and shaped so as define an opening through which the rotation distal indentation passes, wherein the optical member and the mirror have respective rotational shapes about a common rotation axis.

There is further provided, in accordance with an embodiment of the present invention, apparatus including an optical system for use in an endoscope, the optical system having distal and proximal ends and including:

an image sensor, positioned at the proximal end of the optical system;

an optical member having distal and proximal ends, and shaped so as to define a lateral surface, at least a distal portion of which is curved, configured to provide omnidirectional lateral viewing;

a convex mirror, coupled to the distal end of the optical member, and shaped so as define an opening through which distal light passes, wherein the optical member and

the mirror have respective rotational shapes about a common rotation axis;

a light source; and

a power cable, coupled to the light source, and positioned diagonally with respect to the common rotation axis, along a portion of the curved distal portion of the lateral surface of the optical member.

There is still further provided, in accordance with an embodiment of the present invention, apparatus including an optical system for use in an endoscope, the optical system having distal and proximal ends and including:

an image sensor, positioned at the proximal end of the optical system;

an optical member having distal and proximal ends, and shaped so as to define a lateral surface, at least a distal portion of which is curved, configured to provide omnidirectional lateral viewing;

a convex mirror, coupled to the distal end of the optical member, and shaped so as define an opening through which distal light passes to provide forward viewing, wherein the optical member and the mirror have respective rotational shapes about a common rotation axis;

a side-lighting light source, adapted to provide lighting lateral to the optical member;

a forward-lighting light source, adapted to provide lighting distal to the optical member;

a control unit, adapted to alternatingly activate the side-lighting and forward-lighting light sources; and

image processing circuitry, configured to:

process a forward viewing image sensed by the image sensor during a time of activation of the forward-lighting light source and inactivation of the side-lighting light source, and

process an omnidirectional lateral viewing image sensed by the image sensor during a time of activation of the side-lighting light source and inactivation of the forward-lighting light source.

The present invention will be more fully understood from the following detailed description of preferred embodiments thereof, taken together with the drawings, in which:

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a schematic cross-sectional illustration of an optical system for use in an endoscope, in accordance with an embodiment of the present invention;

Figs. 2A and 2B are schematic cross-sectional illustrations of light passing through the optical system of Fig. 1, in accordance with an embodiment of the present invention;

Fig. 3 is a schematic cross-sectional illustration of a light source for use in an endoscope, in accordance with an embodiment of the present invention;

Fig. 4 is a schematic cross-sectional illustration of another light source for use in an endoscope, in accordance with an embodiment of the present invention;

Fig. 5 is a schematic illustration of a lumen within a subject, in accordance with an embodiment of the present invention; and

Fig. 6 is a schematic illustration of a portion of a field of view of the optical system of Fig. 1, in accordance with an embodiment of the present invention.

DETAILED DESCRIPTION OF EMBODIMENTS

Fig. 1 is a schematic cross-sectional illustration of an optical system 20 for use in an endoscope (e.g., a colonoscope), in accordance with an embodiment of the present invention. Optical system 20 comprises an optical assembly 30 and an image sensor 32, such as a CCD or CMOS sensor. Optical system 20 further comprises mechanical support structures, which, for clarity of illustration, are not shown in the figure. Optical system 20 is typically integrated into the distal end of an endoscope (integration not shown).

Optical assembly 30 comprises an optical member 34 having a rotational shape. Typically, at least a distal portion 36 of the optical member is shaped so as to define a curved lateral surface, e.g., a hyperbolic, parabolic, ellipsoidal, conical, or semi-spherical surface. Optical member 34 comprises a transparent material, such as acrylic resin, polycarbonate, or glass. For some applications, all or a portion of the lateral surface of optical member 34 other than portion 36 is generally opaque, in order to prevent unwanted light from entering the optical member.

Optical assembly 30 further comprises, at a distal end thereof, a convex mirror 40 having a rotational shape that has the same rotation axis as optical member 34. Mirror 40 is typically aspheric, e.g., hyperbolic or conical. Alternatively, mirror 40 is semi-spherical. Mirror 40 is typically formed by coating a forward-facing concave portion 42 of optical member 34 with a non-transparent reflective coating, e.g., aluminum, silver, platinum, a nickel-chromium alloy, or gold. Such coating may be performed, for example, using vapor deposition, sputtering, or plating. Alternatively, mirror 40 is formed as a separate element having the same shape as concave portion

42, and the mirror is subsequently coupled to optical member 34.

Optical member 34 is typically shaped so as to define a distal indentation 44 at the distal end of the optical member, i.e., through a central portion of mirror 40. Distal indentation 44 typically has the same rotation axis as optical member 34. A proximal surface 46 of distal indentation 44 is shaped so as to define a lens that focuses light passing therethrough. Alternatively, proximal surface 46 is non-focusing. For some applications, optical member 34 is shaped so as to define a distally-facing protrusion from mirror 40. Alternatively, optical member 34 is shaped without indentation 44, but instead mirror 40 includes a non-mirrored portion in the center thereof.

For some applications, optical member 34 is shaped so as to define a proximal indentation 48 at the proximal end of the optical member. Proximal indentation 48 typically has the same rotation axis as optical member 34. At least a portion of proximal indentation 48 is shaped so as to define a lens 50. For some applications, lens 50 is aspheric.

In an embodiment of the present invention, optical assembly 30 further comprises a distal lens 52 that has the same rotation axis as optical member 34. Distal lens 52 focuses light arriving from the forward (proximal) direction onto proximal surface 46 of distal indentation 44, as described hereinbelow with reference to Fig. 2A. For some applications, distal lens 52 is shaped so as to define a distal convex aspheric surface 54, and a proximal concave aspheric surface 56. Typically, the radius of curvature of proximal surface 56 is less than that of distal surface 54. Distal lens 52 typically comprises a

transparent optical plastic material such as acrylic resin or polycarbonate, or it may comprise glass.

For some applications, optical assembly 30 further comprises one or more proximal lenses 58, e.g., two proximal lenses 58. Proximal lenses 58 are positioned between optical member 34 and image sensor 32, so as to focus light from the optical member onto the image sensor. Typically, lenses 58 are aspheric, and comprise a transparent optical plastic material, such as acrylic resin or polycarbonate, or they may comprise glass.

Reference is now made to Figs. 2A and 2B, which are schematic cross-sectional illustrations of light passing through optical system 20, in accordance with an embodiment of the present invention. Optical system 20 is configured to enable simultaneous forward and omnidirectional lateral viewing. As shown in Fig. 2A, forward light, symbolically represented as lines 80a and 80b, enters optical assembly 30 distal to the assembly. Typically, the light passes through distal lens 52, which focuses the light onto proximal surface 46 of distal indentation 44. Proximal surface 46 in turn focuses the light onto lens 50 of proximal indentation 48, which typically further focuses the light onto proximal lenses 58. The proximal lenses still further focus the light onto image sensor 32, typically onto a central portion of the image sensor.

As shown in Fig. 2B, lateral light, symbolically represented as lines 82a and 82b, laterally enters optical assembly 30. The light is refracted by distal portion 36 of optical member 34, and then reflected by mirror 40. The light then passes through lens 50 of proximal indentation 48, which typically further focuses the light onto proximal lenses 58. The proximal lenses still further focus the

light onto image sensor 32, typically onto a peripheral portion of the image sensor.

As can be seen, the forward light and the lateral light travel through substantially separate, non-overlapping optical paths. The forward light and the lateral light are typically processed to create two separate images, rather than a unified image. Optical assembly 30 is typically configured to provide different levels of magnification for the forward light and the lateral light. The magnification of the forward light is typically determined by configuring the shape of distal lens 52, proximal surface 46, and the central region of lens 50 of proximal indentation 48. On the other hand, the magnification of the lateral light is typically determined by configuring the shape of distal portion 36 of optical member 34 and the peripheral region of lens 50 of proximal indentation 48.

For some applications, the forward view is used primarily for navigation within a body region, while the omnidirectional lateral view is used primarily for inspection of the body region. In these applications, optically assembly 30 is typically configured such that the magnification of the forward light is less than that of the lateral light.

Reference is now made to Fig. 3, which is a schematic cross-sectional illustration of a light source 100 for use in an endoscope, in accordance with an embodiment of the present invention. Although light source 100 is shown and described herein as being used with optical system 20, the light source may also be used with other endoscopic optical systems that provide both forward and lateral viewing.

Light source 100 comprises two concentric rings of LEDs encircling optical member 34: a side-lighting LED ring 102 and a forward-lighting LED ring 104. Each of the rings typically comprises between about 4 and about 12 individual LEDs. The LEDs are typically supported by a common annular support structure 106. Alternatively, the LEDs of each ring are supported by separate support structures, or are supported by optical member 34 (configurations not shown). Alternatively or additionally, light source 100 comprises one or more LEDs (or other lights) located at a different site, but coupled to support structure 106 via optical fibers (configuration not shown). It is thus to be appreciated that embodiments described herein with respect to LEDs directly illuminating an area could be modified, *mutatis mutandis,* such that light is generated at a remote site and conveyed by optical fibers. As appropriate for various applications, suitable remote sites may include a site near the image sensor, a site along the length of the endoscope, or a site external to the lumen.

The LEDs of side-lighting LED ring 102 are oriented such that they illuminate laterally, in order to provide illumination for omnidirectional lateral viewing by optical system 20. The LEDs of forward-lighting LED ring 104 are oriented such that they illuminate in a forward direction, by directing light through optical member 34 and distal lens 52. Typically, as shown in Fig. 3, side-lighting LED ring 102 is positioned further from optical member 34 than is forward-lighting LED ring 104. Alternatively, the side-lighting LED ring is positioned closer to optical member 34 than is the forward-lighting LED ring. For example, the LEDs of the rings may be positioned such that the LEDs of the forward-lighting LED ring do not block light emitted from the LEDs of the side-lighting LED ring, or the side-

lighting LED ring may be placed distal or proximal to the forward-lighting LED ring (configurations not shown).

For some applications, light source 100 further comprises one or more beam shapers and/or diffusers to narrow or broaden, respectively, the light beams emitted by the LEDs. For example, beam shapers may be provided to narrow the light beams emitted by the LEDs of forward-lighting LED ring 104, and/or diffusers may be provided to broaden the light beams emitted by the LEDs of side-lighting LED ring 102.

Reference is now made to Fig. 4, which is a schematic cross-sectional illustration of a light source 120 for use in an endoscope, in accordance with an embodiment of the present invention. Although light source 120 is shown and described as being used with optical system 20, the light source may also be used with other endoscopic optical systems that provide both forward and lateral viewing.

Light source 120 comprises a side-lighting LED ring 122 encircling optical member 34, and a forward-lighting LED ring 124 positioned in a vicinity of a distal end of optical member 34. Each of the rings typically comprises between about 4 and about 12 individual LEDs. The LEDs of side-lighting LED ring 122 are oriented such that they illuminate laterally, in order to provide illumination for omnidirectional lateral viewing by optical system 20. The LEDs of side-lighting LED ring 122 are typically supported by an annular support structure 126, or by optical member 34 (configuration not shown).

The LEDs of forward-lighting LED ring 124 are oriented such that they illuminate in a forward direction. The LEDs of forward-lighting LED ring 124 are typically supported by optical member 34. Light source 120 typically provides

power to the LEDs over at least one power cable 128, which typically passes along the side of optical member 34. (For some applications, power cable 128 is flush with the side of optical member 34.) In an embodiment, power cable 128 is oriented diagonally with respect to a rotation axis 130 of optical member 34, as the cable passes distal portion 36. (In other words, if power cable 128 passes the proximal end of distal portion 36 at "12 o'clock," then it may pass the distal end of distal portion 36 at "2 o'clock.") As described hereinbelow, such a diagonal orientation minimizes or eliminates visual interference that otherwise may be caused by the power cable.

For some applications, light source 120 further comprises one or more beam shapers and/or diffusers to narrow or broaden, respectively, the light beams generated by the LEDs. For example, diffusers may be provided to broaden the light beams generated by the LEDs of side-lighting LED ring 122 and/or forward-lighting LED ring 124.

Although light source 100 (Fig. 3) and light source 120 (Fig. 4) are described herein as comprising LEDs, the light sources may alternatively or additionally comprise other illuminating elements. For example, the light sources may comprise optical fibers illuminated by a remote light source, e.g., external to the endoscope or in the handle of the endoscope.

In an embodiment of the present invention, optical system 20 comprises a side-lighting light source and a forward-lighting light source. For example, the side-lighting light source may comprise side-lighting LED ring 102 or side-lighting LED ring 122, or any other side-lighting light source known in the art. Similarly, the forward-lighting light source may comprise forward-lighting LED ring 104 or forward-lighting LED ring 124, or any other

forward-lighting light source known in the art. Optical system 20 is configured to alternatingly activate the side-lighting and forward-lighting light sources, typically at between about 10 and about 20 Hz, although faster or slower rates may be appropriate depending on the desired temporal resolution of the imaging data.

For some applications, only one of the light sources is activated for a desired length of time (e.g., greater than one minute), and video data are displayed based on the images illuminated by that light source. For example, the forward-lighting light source may be activated during initial advancement of a colonoscope to a site slightly beyond a target site of interest, and the side-lighting light source may be activated during slow retraction of the colonoscope, in order to facilitate close examination of the target site.

Image processing circuitry of the endoscope is configured to process forward-viewing images that were sensed by image sensor 32 during activation of the forward-viewing light source, when the side-viewing light source was not activated. The image processing circuitry is configured to process lateral images that were sensed by image sensor 32 during activation of the side-lighting light source, when the forward-viewing light source was not activated. Such toggling reduces any interference that may be caused by reflections caused by the other light source, and/or reduces power consumption and heat generation. For some applications, such toggling enables optical system 20 to be configured to utilize at least a portion of image sensor 32 for both forward and side viewing.

In an embodiment, a duty cycle is provided to regulate the toggling. For example, the lateral images may be sampled for a greater amount of time than the forward-

viewing images (e.g., at time ratios of 1.5 : 1, or 3 : 1). Alternatively, the lateral images may be sampled for a lesser amount of time than the forward-viewing images.

In an embodiment, in order to reduce a possible sensation of image flickering due to the toggling, each successive lateral image is continuously displayed until the next lateral image is displayed, and, correspondingly, each successive forward-viewing image is continuously displayed until the next forward-viewing image is displayed. (The lateral and forward-viewing images are displayed on different portions of a monitor.) Thus, for example, even though the sampled forward-viewing image data may include a large amount of dark video frames (because forward illumination is alternated with lateral illumination), substantially no dark frames are displayed.

Reference is now made to Fig. 5, which is a schematic illustration of a lumen 200 within a subject, such as a gastrointestinal (GI) tract, in accordance with an embodiment of the present invention. An item of interest 202, such as a suspected tumor, is being examined. An endoscopic system comprises an optical system and image processing circuitry. The optical system is typically, but not necessarily, configured to enable omnidirectional lateral viewing (e.g., as described hereinabove).

The image processing circuitry is configured to capture a series 220 of longitudinally-arranged image segments 222 of an internal wall 230 of lumen 200, while the optical system is moving through the lumen (i.e., being either withdrawn or inserted). The image processing circuitry stitches together individual image segments 222 into a combined continuous image, either in real time and/or for later viewing. The image processing circuitry

typically accurately aligns image segments 222 for such stitching using one or both of the following techniques:

- Image segments 222 are captured such that adjoining segments share an overlapping portion of the image. The image processing circuitry uses information from this overlapping portion to register successive segments.
- The endoscopic system detects the motion of the optical system in order to determine the location of the optical system at different points in time. The image processing circuitry uses the location information to appropriately combine the segments. For example, the endoscopic system may detect the motion of the optical system by sensing markers on an elongate carrier through which the optical system is passed. Alternatively, the endoscopic system directly detects the location of the optical system using one or more position sensors, as is known in the art of medical position sensing.

Alternatively or additionally, stitching techniques are used that are known in the art of panoramic image creation and processing.

This image capture and processing technique generally enables higher-resolution imaging of a large field than is possible using conventional techniques, *ceteris paribus*. Using conventional techniques, a relatively wide area 236 must generally be captured simultaneously in order to provide a useful image to the physician. In contrast, the techniques described herein enable the display of wide area 236 while only capturing relatively narrow image segments 222. This enables the optics of the optical system to be

focused narrowly on an area of wall 230 having a width approximately equal to that of each image segment 222.

Reference is now made to Fig. 6, which is a schematic illustration of a portion of a field of view 250 of optical system 20, in accordance with an embodiment of the present invention. As described hereinabove with reference to Fig. 4, in an embodiment power cable 128 is oriented diagonally with respect to a rotation axis 130 of optical member 34 (a line 252 in Fig. 6 is parallel to rotation axis 130 of Fig. 4). As a result, power cable 128 blocks the fixed areas of the surface of optical member 34 over which the power cable passes, resulting in blind spots as optical system 20 is moved through the lumen of the subject.

For example, when distal portion 36 of optical member 34 is in a first position 256, an area of interest 254 in a visual area 260 of an image segment 262 is blocked. As optical system 20 is moved through the lumen, e.g., in the direction indicated by an arrow 264, distal portion 36 arrives at a second position 266. In this position, area of interest 254 is now visible in a visual area 268 of an image segment 270. For some applications, the image processing circuitry replaces the blocked image of area of interest 254, which was captured in visual area 260, with the visible image of area of interest 254, which was captured in visual area 268. In this manner, the image processing circuitry constructs a complete, unobstructed image of field of view 250.

In an embodiment of the present invention, image processing circuitry produces a stereoscopic image by capturing two images of each point of interest from two respective sequential viewpoints while the optical system is moving, e.g., through a lumen in a subject. For each set of two images, the location of the optical system is

determined, such as by using the location determination techniques described hereinabove. Using this location information, the image processing software processes the two images in order to generate a stereoscopic image. Appropriate stereoscopic image processing techniques will be evident to those skilled in the art, having read the present application.

In an embodiment of the present invention, image processing circuitry converts a lateral omnidirectional image of a lumen in a subject to a two-dimensional image. Typically, the image processing circuitry longitudinally cuts the omnidirectional image, and then unrolls the omnidirectional image onto a single plane. This technique allows, for example, creation of a composite photograph of a length of the colon of a patient, seen as if the colon were opened by a longitudinal incision.

Although embodiments of the present invention have been described with respect to medical endoscopes, the techniques described herein are also applicable to other endoscopic applications, such as industrial endoscopy (e.g., pipe inspection).

It will be appreciated by persons skilled in the art that the present invention is not limited to what has been particularly shown and described hereinabove. Rather, the scope of the present invention includes both combinations and subcombinations of the various features described hereinabove, as well as variations and modifications thereof that are not in the prior art, which would occur to persons skilled in the art upon reading the foregoing description.

CLAIMS

1. Apparatus comprising an optical system for use in an endoscope, the optical system having distal and proximal ends and comprising:

an image sensor, positioned at the proximal end of the optical system;

an optical member having distal and proximal ends, and shaped so as to define:

a lateral surface, at least a distal portion of which is curved, configured to provide omnidirectional lateral viewing,

a distal indentation in the distal end of the optical member, and

a proximal indentation in the proximal end of the optical member;

a convex mirror, coupled to the distal end of the optical member, and shaped so as define an opening through which the distal indentation passes; and

a distal lens, positioned distal to the mirror,

wherein the optical member, the mirror, and the distal lens have respective rotational shapes about a common rotation axis, and

wherein the optical member and the distal lens are configured to provide different levels of magnification for distal light arriving at the image sensor through the distal end of the optical system, and lateral light arriving at the image sensor through the curved distal portion of the lateral surface of the optical member.

2. Apparatus comprising an optical system for use in an endoscope, the optical system having distal and proximal ends and comprising:

an image sensor, positioned at the proximal end of the optical system;

an optical member having distal and proximal ends, and shaped so as to define:

a lateral surface, at least a distal portion of which is curved, configured to provide omnidirectional lateral viewing, and

a distal indentation in the distal end of the optical member, the indentation shaped so as to define a lens at a proximal surface thereof; and

a convex mirror, coupled to the distal end of the optical member, and shaped so as define an opening through which the rotation distal indentation passes, wherein the optical member and the mirror have respective rotational shapes about a common rotation axis.

3. Apparatus comprising an optical system for use in an endoscope, the optical system having distal and proximal ends and comprising:

an image sensor, positioned at the proximal end of the optical system;

an optical member having distal and proximal ends, and shaped so as to define a lateral surface, at least a distal portion of which is curved, configured to provide omnidirectional lateral viewing;

a convex mirror, coupled to the distal end of the optical member, and shaped so as define an opening through which distal light passes, wherein the optical member and the mirror have respective rotational shapes about a common rotation axis;

a light source; and

a power cable, coupled to the light source, and positioned diagonally with respect to the common rotation axis, along a portion of the curved distal portion of the lateral surface of the optical member.

4. Apparatus comprising an optical system for use in an endoscope, the optical system having distal and proximal ends and comprising:

an image sensor, positioned at the proximal end of the optical system;

an optical member having distal and proximal ends, and shaped so as to define a lateral surface, at least a distal portion of which is curved, configured to provide omnidirectional lateral viewing;

a convex mirror, coupled to the distal end of the optical member, and shaped so as define an opening through which distal light passes to provide forward viewing, wherein the optical member and the mirror have respective rotational shapes about a common rotation axis;

a side-lighting light source, adapted to provide lighting lateral to the optical member;

a forward-lighting light source, adapted to provide lighting distal to the optical member;

a control unit, adapted to alternatingly activate the side-lighting and forward-lighting light sources; and

image processing circuitry, configured to:

process a forward viewing image sensed by the image sensor during a time of activation of the forward-lighting light source and inactivation of the side-lighting light source, and

process an omnidirectional lateral viewing image sensed by the image sensor during a time of activation of the side-lighting light source and inactivation of the forward-lighting light source.

FIG. 1

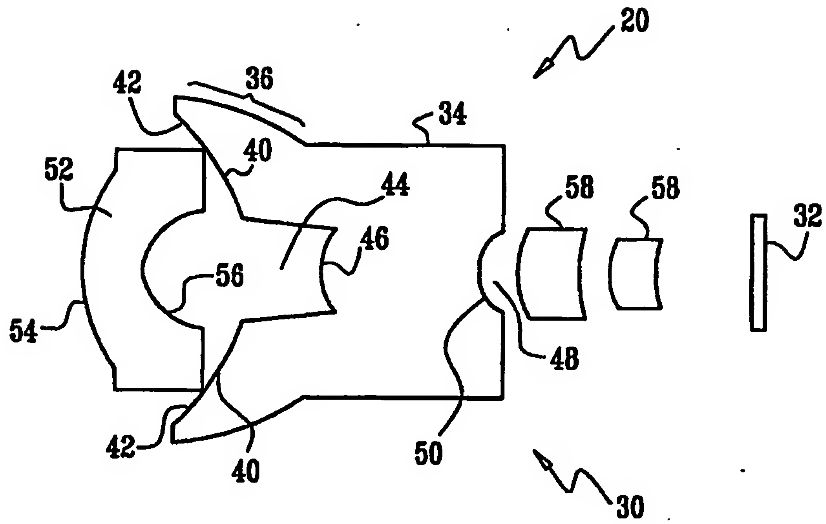
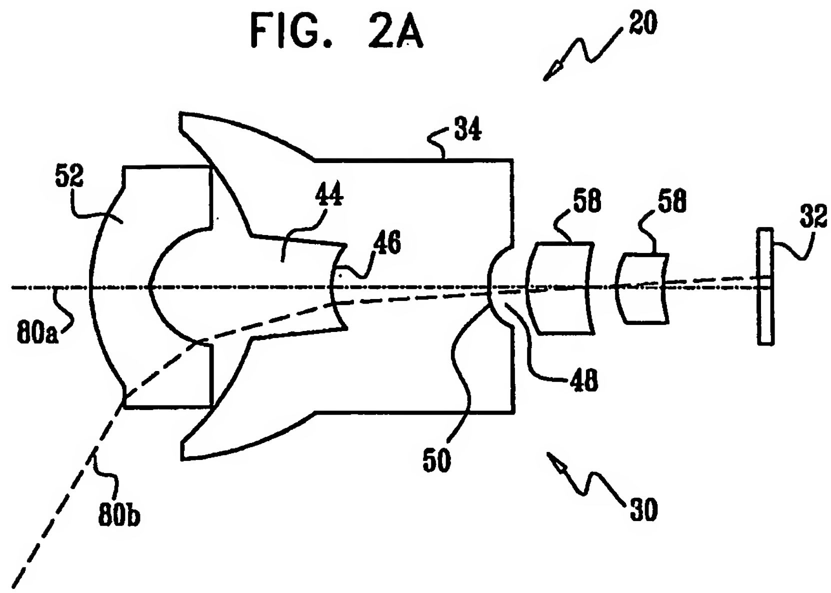


FIG. 2A


20
34
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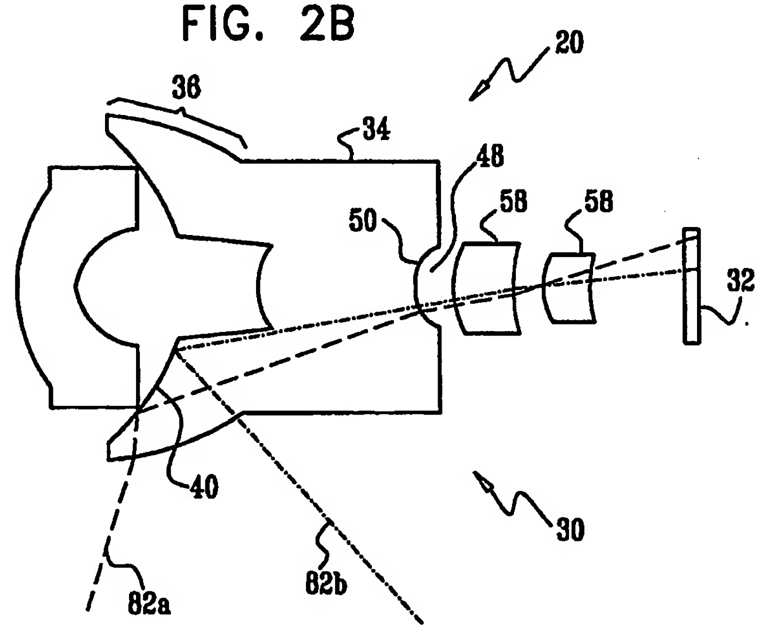
44
46
58
58
32
80a
48
50
80b
30

FIG. 2B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32
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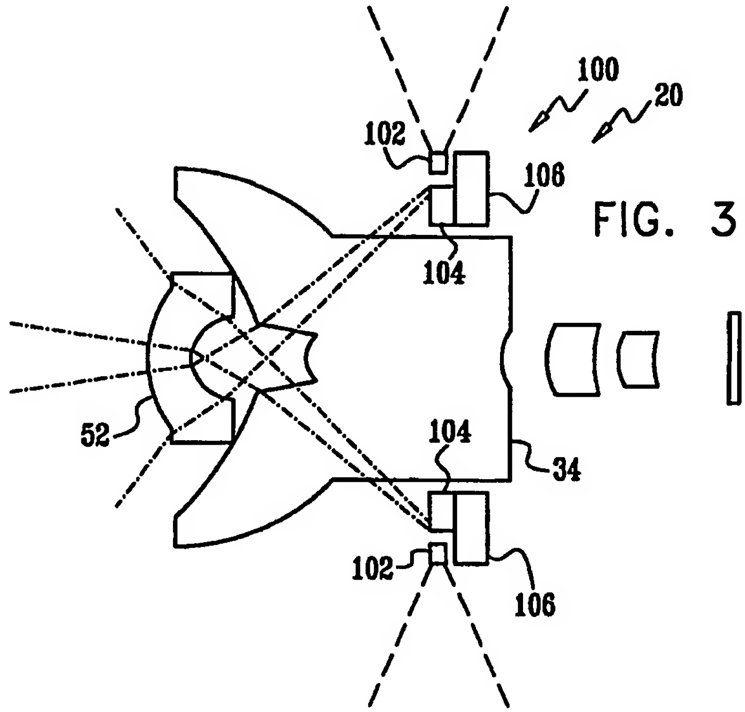
30
82b
82a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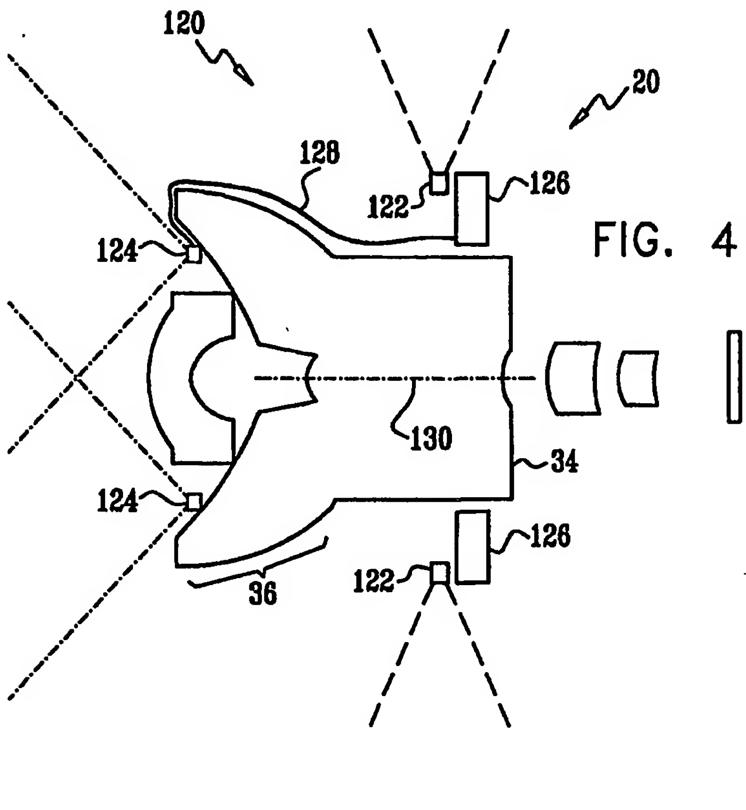
104
34
102
106

FIG. 3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122
124
130
34
124
126
36
122

FIG. 4

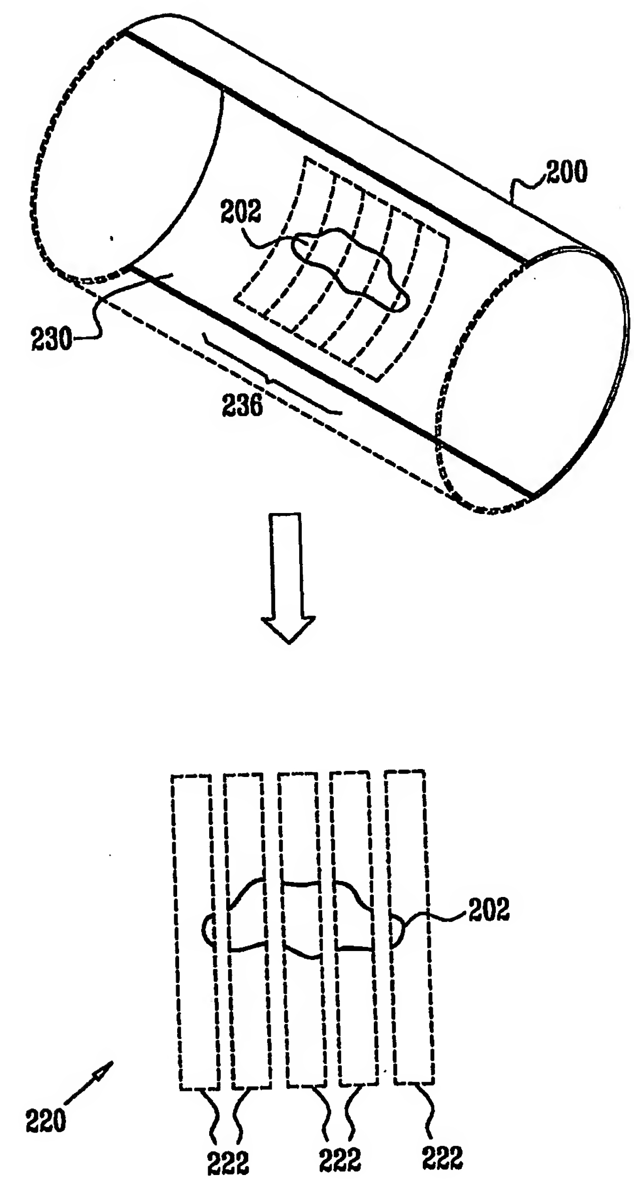
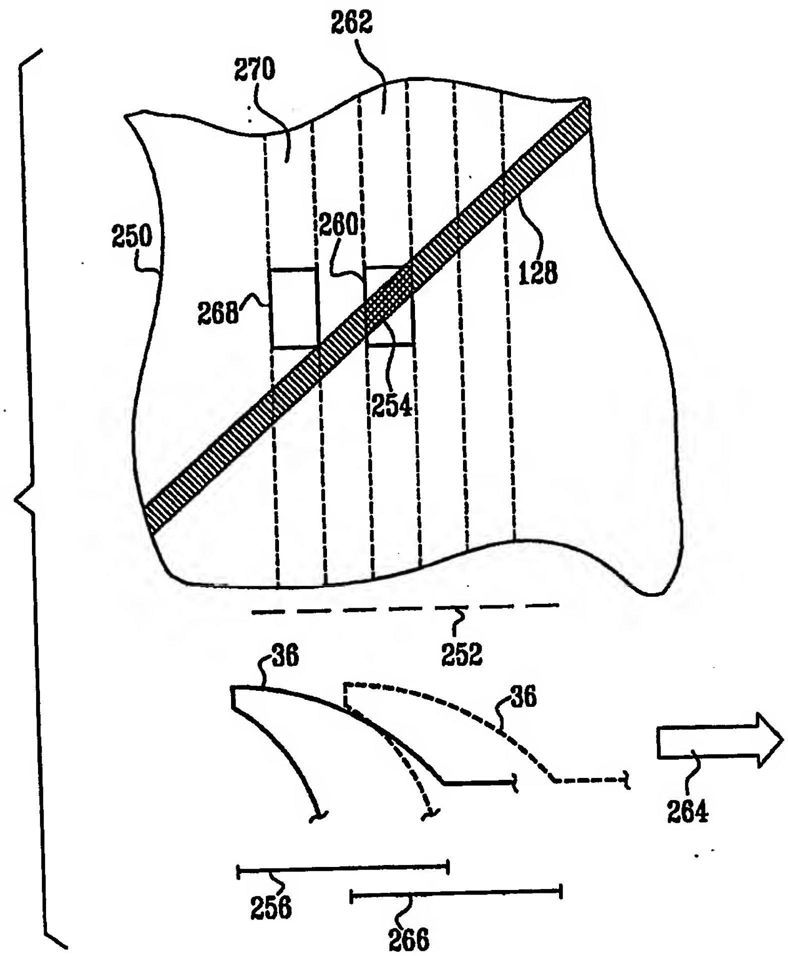


FIG. 5

FIG. 6



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